THE HIRNANTIAN GRAPTOLITES *NORMALOGRAPTUS PERSCULPTUS* AND '*GLYPTOGRAPTUS*' *BOHEMICUS*: STRATIGRAPHICAL CONSEQUENCES OF THEIR SYNONYMY

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ABSTRACT. It is demonstrated that '*Glyptograptus*' *bohemicus* is a junior subjective synonym of *Normalograptus persculptus*. The first appearance of *N. persculptus* appears to be diachronous, posing problems for Hirnantian biozonation. In China, *N. persculptus* co-occurs with *N. extraordinarius*. We favour here an extension downwards of the existing *persculptus* Biozone, the base being defined by the incoming of *N. persculptus*, with the lower part of the biozone designated the *extraordinarius* Subzone.

THERE has not been agreement among graptolite workers as to the taxonomic and stratigraphical relations between *Normalograptus persculptus* (Elles and Wood, 1907) and '*Glyptograptus*' *bohemicus* Marek, 1955. Many authors (e.g. Štorch 1982, 1988; Wang *et al.* 1983; Chen and Lin 1984; Li 1984; Mu and Lin 1984; Ni 1984; Fu and Song 1986; Wang 1987; Mu 1988; Fang *et al.* 1990; Melchin *et al.* 1991) considered the two taxa to be distinct and used them as index species for two separate biozones within the Hirnantian Stage (Ashgill Series, Ordovician). Below the *persculptus* Biozone, which is recognized globally, a *bohemicus* Biozone has been introduced in the graptolite biozonal schemes of Bohemia, China and Arctic Canada. Other authors (Koren' and Sobolevskaya 1983; VandenBerg *et al.* 1984; Štorch 1994), however, have considered *N. persculptus* and '*G.*' *bohemicus* to be synonyms. Herein we redescribe the type and all other available Bohemian specimens of '*G.*' *bohemicus* and compare them with Welsh material of *N. persculptus*. Brief comparison with selected Chinese material is also included. We demonstrate that '*G.*' *bohemicus* is a junior subjective synonym of *N. persculptus* and discuss the stratigraphical consequences of this synonymy.

STRATIGRAPHICAL FRAMEWORK FOR THE BOHEMIAN MATERIAL

All the Bohemian specimens of '*G.*' *bohemicus* come from the uppermost beds of the Kosov Formation (Text-figs 1–2). This is a glacio-eustatically controlled regressive-transgressive sequence, *c.* 100 m thick, of Hirnantian age. Diverse, deep-shelf Rawtheyan faunas, which characterize the clayey shales of the underlying Králův Dvůr Formation, disappear just below the base of the Kosov Formation (Štorch and Mergl 1989), and are replaced by the low-diversity *Mucronaspis* Assemblage, which occurs in Hirnantian deeper-water environments. The base of the Kosov Formation is marked by two levels of pebbly glacio-marine diamictites (Brenchley and Štorch 1989). These suggest that, in the early Hirnantian, at an early stage of regression, floating ice extended over the Prague Basin. The continuing regression is documented by the overlying, rhythmically bedded tempestites. The middle part of the Kosov Formation is suggestive of a temporary sea-level rise, being composed of a shaly sequence with few thin siltstone intercalations.

The upper part of the Kosov Formation is represented by another rhythmically bedded tempestite unit. This has, above its sharp erosional base, several thick beds of coarse sandstones and

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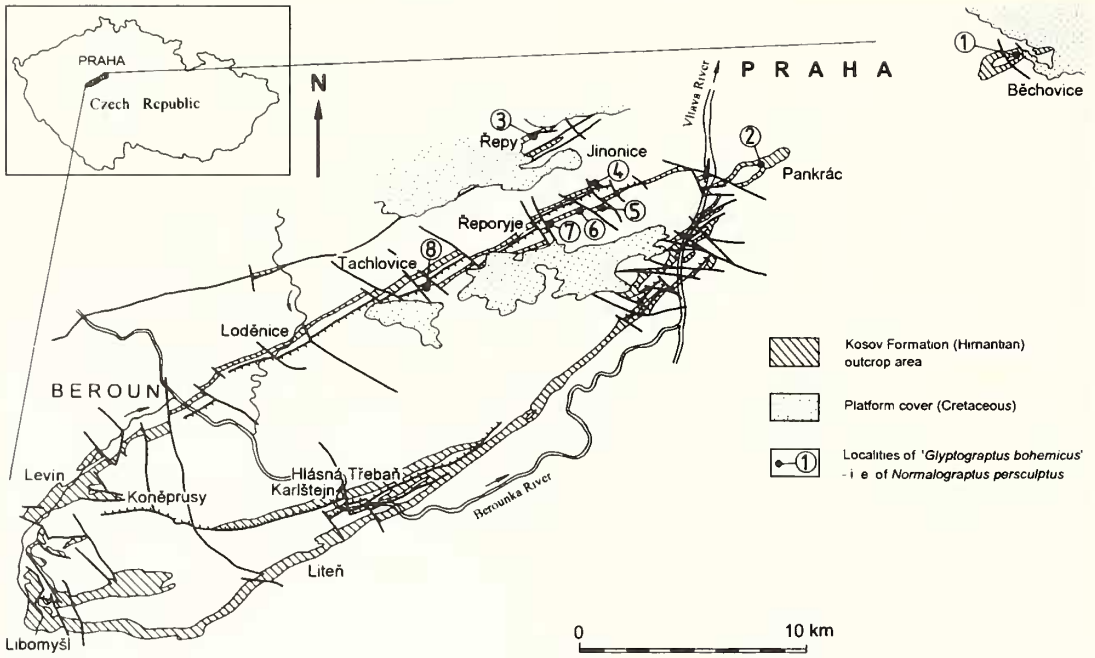
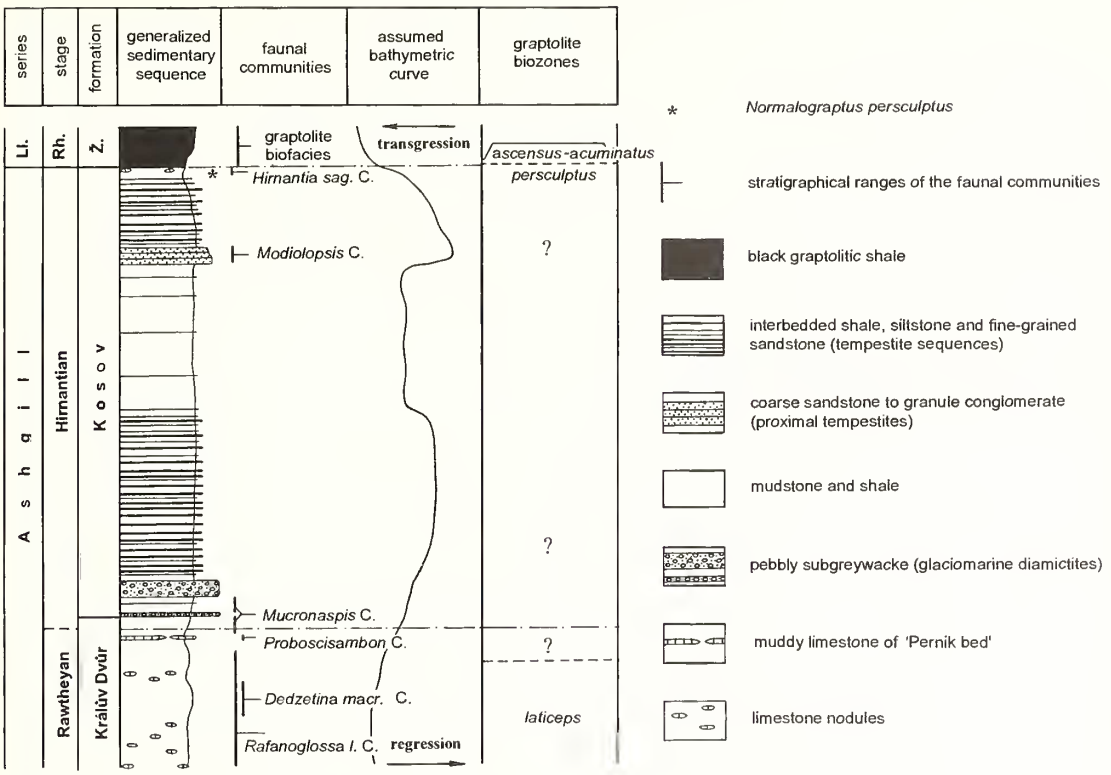


TEXT-FIG. 1. Localities where *Normalograptus persculptus* (formerly '*Glyptograptus*' *bohemicus*) has been found in the Barrandian area in Bohemia, with Gauss-Krueger grid references: 1 – Běchovice, X5551248, Y3457177; 2 – Pankrác, X5547359, Y3460644; 3 – Řepy, X548661, Y3450474; 4 – Nové Butovice, X5546447, Y3453087; 5 – Jinonice-Nová Ves, X5545574, Y3453632; 6 – Velká Ohrada, X5545512, Y3452675; 7 – Řeporyje, X5445061, Y3451663; 8 – Tachlovice, X5547359, Y3446006.

conglomerates. According to Brenchley and Štorch (1989), these indicate a second regressive event with the shelf channelled and coarse material supplied from the shore. The sedimentary structures described by Brenchley and Štorch (1989), ichnofacies described by Mikuláš (1993), and very low diversity bivalve assemblage listed by Havlíček (1982) all come from the period of maximum glacio-eustatic regression at the base of the upper tempestite unit of the Kosov Formation. The bathymetric curve of Štorch (1990) for the Kosov Formation fits well the bathymetric changes suggested by, for example, Brenchley (1984) and Brenchley *et al.* (1991). The remainder of the upper, rhythmically bedded tempestite unit was deposited during a transgression which accelerated towards the top of the Kosov Formation.

The uppermost part of the Kosov Formation was deposited under deeper-subtidal conditions, well below storm-wave base. In the north-east part of the Barrandian area it is composed of heavily bioturbated mudstones, with a varied, brachiopod-dominated *Hirnantia* Fauna (Marek and Havlíček 1967; Štorch 1986) and '*G.*' *bohemicus*. This fauna has been recorded at Běchovice, Jinonice-Nová Ves, Nové Butovice, Pankrác, Řepy, Tachlovice (borehole) and Velká Ohrada (Text-fig. 1).

Both the *Hirnantia* Fauna and the graptolite rhabdosomes are confined to this rather thin (50 mm–4·5 m thick) horizon. The highest identifiable '*G.*' *bohemicus*, found together with uncommon brachiopods, were about 70 mm below the base of the overlying black Silurian shales, which yield *Normalograptus angustus* (Perner), *Akidograptus ascensus* Davies and *Neodiplograptus lanceolatus* Štorch and Serpagli. At some localities described by Štorch (1986; Řepy, Vočkov and Želkovice) 20–30 mm of black and white, laminated shale forms the transition from the pale mudstones to the Silurian black shales, without any apparent gap in sedimentation. This



TEXT-FIG. 2. The upper Ashgill stratigraphy of the Barrandian area, Bohemia, showing the stratigraphical level of Bohemian specimens of *Normalograptus persculptus* (formerly '*Glyptograptus*' *bohemicus*). The thickness of the Kosov Formation varies between 40 and 150 m. Abbreviations: C. – community; Ll. – Llandovery; Rh. – Rhuddanian; Ž. – Želkovice Formation. Not drawn to scale.

transitional bed, still below the first appearance of *A. ascensus*, contains poorly preserved normalograptids, including the specimens referred by Štorch (1982, 1986) to '*G. bohemicus-persculptus*'.

The *Hirnantia* Fauna and '*G.*' *bohemicus* have been recorded in the Barrandian area at the same level from which *Normalograptus persculptus* and associated graptolites are reported elsewhere. Although the two species could be regarded as coeval, palaeogeographically restricted subspecies, because of their identical dimensions and morphology, we prefer to consider '*G.*' *bohemicus* to be a junior subjective synonym of *N. persculptus* (Elles and Wood).

Institutional abbreviations are: GSM, British Geological Survey, Keyworth, Nottingham; L, National Museum, Prague; PŠ, Štorch collection, Czech Geological Survey, Prague.

SYSTEMATIC PALAEONTOLOGY

Family NORMALOGRAPTIDAE Štorch and Serpagli, 1993

Genus NORMALOGRAPTUS Legrand, 1987

Type species. By original designation, *Climacograptus scalaris normalis* Lapworth, 1877, from the Birkhill Shales, Dob's Linn, Scotland.

Diagnosis (modified from Melchin and Mitchell 1991). Rhabdosome suboval to nearly circular in cross section. Median septum straight or slightly wavy in the proximal part, usually complete. Early astogeny of Pattern H, with th2 or, rarely, some later theca dicalycal. Proximal end relatively narrow, rounded, asymmetrical. Climacograptid to almost glyptograptid thecae have angular or sigmoidal genicular curvature.

Remarks. The original conception of the genus, reflected in the diagnoses given by Legrand (1987) and Štorch and Serpagli (1993), has been extended to embrace the late Ordovician and early Silurian glyptograptid-like species with Pattern H astogeny.

Normalograptus persculptus (Elles and Wood, 1907)

Text-figures 3–5

1865 *Diplograpsus persculptus* (Salter?), Salter, p. 25 [see Strachan 1971].
1907 *Diplograptus* (*Glyptograptus*) *persculptus* Salter; Elles and Wood, p. 257, pl. 31, fig. 7a–c; text-fig. 176a–b.
1929 *Glyptograptus* aff. *persculptus* Salter; Davies, p. 10, text-fig. 11A.
1929 *Glyptograptus persculptus* mut.; Davies (*pars*), p. 11, text-figs 11, 13, 16–19 (*non* 12, 14).
1929 *Glyptograptus persculptus* mut. *omega* nov., Davies, text-figs 15, 20.
1955 *Glyptograptus bohemicus* Marek, p. 7, pl. 1, figs 1–4.
1971 *Glyptograptus* (*G.*) *persculptus persculptus* (Salter); Strachan, p. 37.
1973 *Glyptograptus persculptus* (Salter); Mikhaylova, p. 15, pl. 3, figs 4–6.
non 1974 *Glyptograptus persculptus* (Salter); Hutt, p. 28, pl. 8, figs 9–12.
1975 *Glyptograptus persculptus* (Salter); Bjerreskov, p. 30, text-fig. 11a–c.
1977 *Glyptograptus bohemicus* Marek; Jaeger, pl. 1, figs 4, 6, 9, 11, 17.
1977 *Glyptograptus* aff. *bohemicus* Marek; Koren' and Sobolevskaya, figs 5–7.
1977 *Glyptograptus persculptus* (Salter); Rickards *et al.*, pl. 2, fig. 4, text-figs 8, 53
1978 *Glyptograptus persculptus* (Salter); Sennikov, p. 142, text-fig. 3i, k.
1980 *Glyptograptus*? *persculptus* (Salter); Koren' *et al.*, pl. 43, figs 2–3.
1980 *Glyptograptus*? *persculptus* (Salter) forma B; Koren' *et al.*, p. 150, pl. 45, figs 1–6; pl. 46, figs 1–6 (?7–8); text-fig. 45a–zh.
1982 *Glyptograptus bohemicus* Marek; Štorch, pl. 2, figs 5–6.
1983 *Glyptograptus persculptus* Salter; Koren' and Sobolevskaya, p. 144, pl. 42, figs 4–10; pl. 43; text-fig. 54 (*pars*).
1983 *Diplograptus bohemicus* (Marek); Mu *et al.* (*pars*), pl. 2, figs 3, 10 (*non* 4).
1983 *Glyptograptus persculptus* (Salter); Wang *et al.*, p. 139, pl. 8, figs 3–6; pl. 9, figs 5, 10–11.
1983 *Diplograptus bohemicus* (Marek); Wang *et al.*, pl. 7, figs 1–3, ?11.
1983 *Glyptograptus persculptus* (Salter); Williams, p. 622, pl. 66, figs 1–3.
1984 *Glyptograptus persculptus* (Salter); Chen and Lin, p. 193, pl. 1, figs 1–6; pl. 2, figs 3–9; text-fig. 1.
1984 *Diplograptus bohemicus* (Marek); Ge, p. 411, pl. 3, figs 10–14, ?15; text-fig. 3.
1984 *Diplograptus bohemicus* (Marek); Li, p. 335, pl. 8, fig. 6, ?1–5.
1984 *Glyptograptus persculptus* (Salter); Lin and Chen, pl. 1, figs 1–2.
?1984 *Glyptograptus lungmaensis* Sun; Lin and Chen (*pars*), p. 209, pl. 1, figs 3, 6 (*non* 4–5).
?1984 *Diplograptus bohemicus* (Marek); Mu and Lin, p. 53, pl. 3, figs 1–3.
1984 *Glyptograptus persculptus* (Salter); Mu and Lin, p. 54, pl. 3, fig. 6; pl. 6, fig. 9.
1984 *Diplograptus bohemicus* (Marek); Ni, p. 323, pl. 2, figs 6–8.
1984 *Glyptograptus*? *persculptus* (Salter); VandenBerg *et al.*, p. 10, figs 8–9.
1986 *Diplograptus bohemicus* (Marek); Fu and Song, p. 76, pl. 4, fig. 6 (?*non* 5); text-fig. 6g.
1986 *Glyptograptus persculptus* (Salter); Fu and Song, p. 80, pl. 4, figs 23–24, (?*non* 22).
1986 *Glyptograptus bohemicus* Marek; Štorch, pl. 3, fig. 8.
?1987 *Glyptograptus persculptus* (Salter); Wang, p. 370, pl. 45, fig. 1.
1987 *Diplograptus bohemicus* (Marek); Wang, p. 375, pl. 43, fig. 1.
1990 *Diplograptus bohemicus* (Marek); Fang *et al.*, p. 46, pl. 1, figs 11–12; pl. 2, figs 2–3; pl. 4, fig. 6.

1990 *Glyptograptus persculptus-sinuatus* transient; Fang *et al.*, p. 60, pl. 8, figs 2–3, 6.
1993 *Diplograptus bohemicus* (Marek); Mu *et al.*, p. 129, pl. 21, figs 1–3, ?4–5.
1994 *Normalograptus*? *persculptus* (Elles and Wood); Zalasiewicz and Tunnicliff, p. 704, fig. 5a–c.

Lectotype. Designated by Williams 1983; GSM 11782 from Salter's collection; Ogofau, Pumpsaint, Dyfed, Wales; figured Williams 1983, plate 66, figure 3.

Material. Eighteen specimens of '*Glyptograptus*' *bohemicus* (including the type material of Marek 1955) from the Barrandian area (Bohemia); most are complete, preserved flattened or in partial relief. Numerous specimens of *Normalograptus persculptus* from localities in mid-Wales, preserved flattened and in moderate to full relief. One of us (DKL) has also examined specimens from China figured by Ge (1984), Li (1984), Mu and Lin (1984) and Ni (1984). All specimens are from the Hirnantian (late Ordovician) *N. persculptus* Biozone.

Diagnosis. Rhabdosome straight, widening from 1·0 mm (0·8 mm in relief) to a maximum of 2·0–2·5 mm at a distance of 10–15 mm from the proximal end; median septum complete in early populations, slightly wavy in specimens preserved in relief. Successive delay in the insertion of the median septum appears in stratigraphically late populations. Alternate to subalternate sigmoidally curved thecae of glyptograptid appearance become strongly geniculate in flattened rhabdosomes; thecae overlap for half of their length and number 5–6 in the proximal 5 mm and 8–10 in 10 mm distally.

Description (of Bohemian material). The rhabdosome is up to 28 mm long, excluding the virgella and nema. It widens from 0·8 mm (1·1–1·3 mm when flattened) at the aperture of th1[1] to 1·1 mm (1·6 mm when flattened) at th3[1], and reaches a maximum of 1·6–1·7 mm (1·9–2·3 mm when flattened) within 8–10 mm of the proximal end. Thecae number 5·5–5·8 in the proximal 5 mm. Distally the thecal count decreases to 10–10·5 in 10 mm.

The sicula, visible for at least 1 mm in obverse view, is conical, with a *c.* 2 mm long virgella. The sicular aperture has a diameter of 0·2–0·25 mm. Th1[1] grows downwards, then, 0·15–0·25 mm below the sicular aperture, bends abruptly upwards. The distance between the sicular aperture and the aperture of th1[1] is 0·85–0·9 mm. Th1[2] grows upwards for its entire length and this gives a distinctive, asymmetrical appearance to the proximal end.

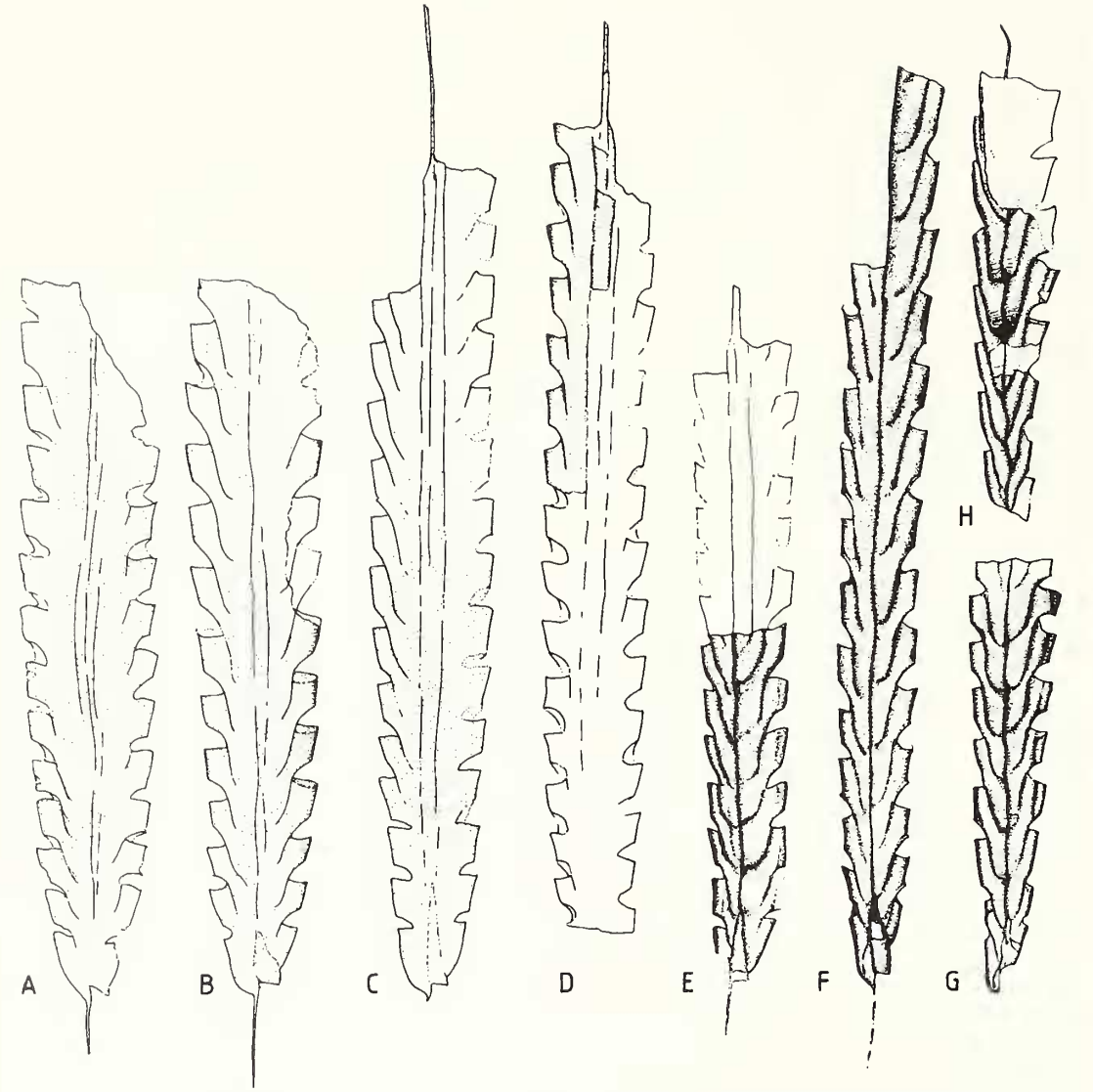
The appearance of the thecae depends upon preservation. Sigmoidally curved thecae with sharp genicula are typical of flattened (including the type) material (from the Jinonice-Nová Ves and Velká Ohrada sections; see e.g. Text-fig. 3A, C). Their supragenicular walls are straight, inclined at *c.* 10° to the rhabdosome axis. Specimens preserved in low relief (from Jinonice, Řepy and Pankrác) and moderate relief (from Pankrác) are of more glyptograptid appearance (Text-fig. 3F–H), but they are still strongly geniculate in some cases. Thecal apertures are straight, horizontal or slightly everted. Thecal excavations occupy *c.* one-fifth of the dorso-ventral width. The subalternate distal thecae are 1·5–1·8 mm long and overlap for up to half their length. Interthecal septa reach to about the level of the aperture of the preceding theca.

The median septum appears to be complete. It is slightly undulating in the proximal part of the rhabdosome. The rhabdosome commonly becomes uniserial distally. The nema is distinctly thickened at the base, probably as a result of distal prolongation of the median septum.

Specimens of *N. persculptus* from mid-Wales are illustrated in Text-figures 4D–E and 5 for comparison with the Bohemian material described above.

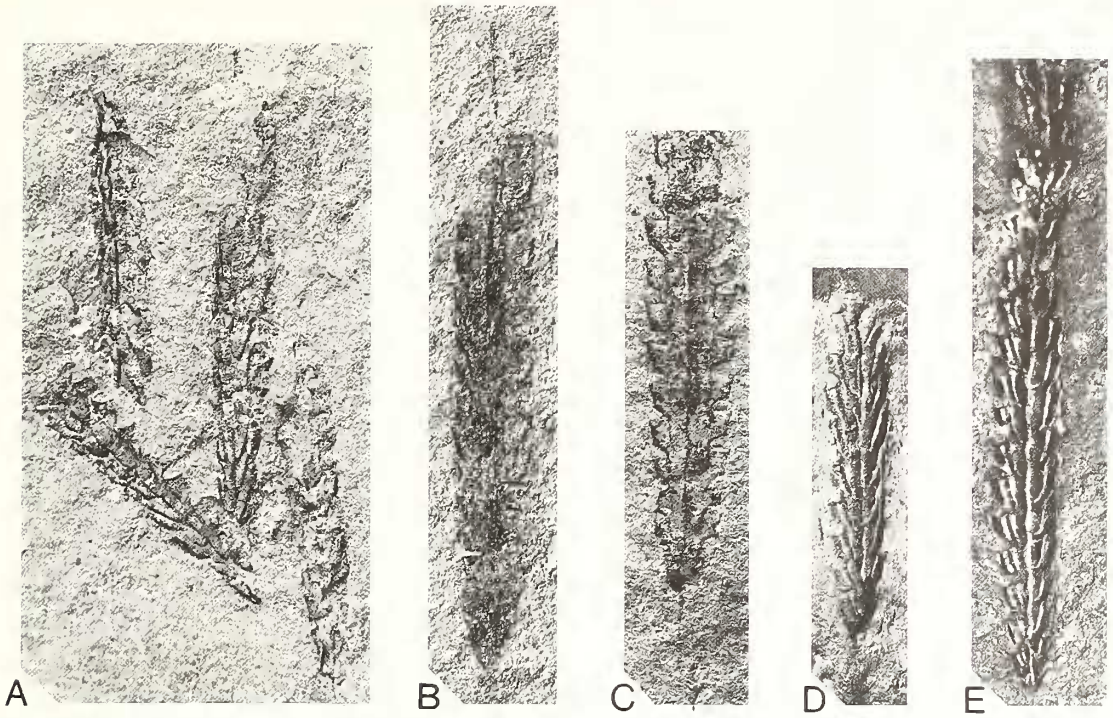
Remarks. Elles and Wood (1907) are regarded here as the authors of *N. persculptus*; Salter (1865) neither figured nor described this species (see discussion in Williams 1983 and Zalasiewicz and Tunnicliff 1994).

The Bohemian material of '*G.*' *bohemicus* agrees well with the Welsh material illustrated herein, and with the British and Scandinavian specimens of *N. persculptus* described by Williams (1983) and Bjerreskov (1975) respectively, as well as the material described by Koren' *et al.* (1980) from Kazakhstan, by Koren' and Sobolevskaya (1983) from Siberia, and by VandenBerg *et al.* (1984) from Australia (Table 1). The distal end of Bohemian rhabdosomes is, however, more commonly uniserial. This latter tendency has been illustrated by Williams (1983) in *Normalograptus venustus venustus* (Legrand), by Lin and Chen (1984) in '*Glyptograptus*' *lungmaensis* Sun and



TEXT-FIG. 3. Bohemian specimens of *Normalograptus persculptus*. A, PŠ 648a; flattened specimen, with periderm. B, PŠ 278/2; preserved in very low relief, with periderm. C, L 14651, holotype of '*Glyptograptus*' *bohemicus*; flattened, partly limonitized film. D, PŠ 278/1; very low relief external mould with some periderm. E, L 14650; preserved in low relief, distally as an external mould. F, PŠ 130; preserved in low relief, with periderm. G-H, PŠ 662a (two rhabdosomes on one slab); preserved in low to moderate relief. Localities: A, Velká Ohrada; B–E, Jinonice-Nová Ves; F, Řepy; G–H, Pankrác. All ×8.

'*Climacograptus*' *wangjiawanensis* Mu and Lin, by Ge (1984) in '*Diplograptus*' *maturatus* Mu and Ni, and commonly in the rhabdosomes referred to '*G.*' *bohemicus* in China. A specimen of *N. persculptus* with four uniserial distal thecae is present in our collections from Rhayader, Wales. The presence of a uniserial distal portion, perhaps the result of some astogenetic mutation, cannot be used as a morphological criterion for separating '*G.*' *bohemicus* from *N. persculptus*.

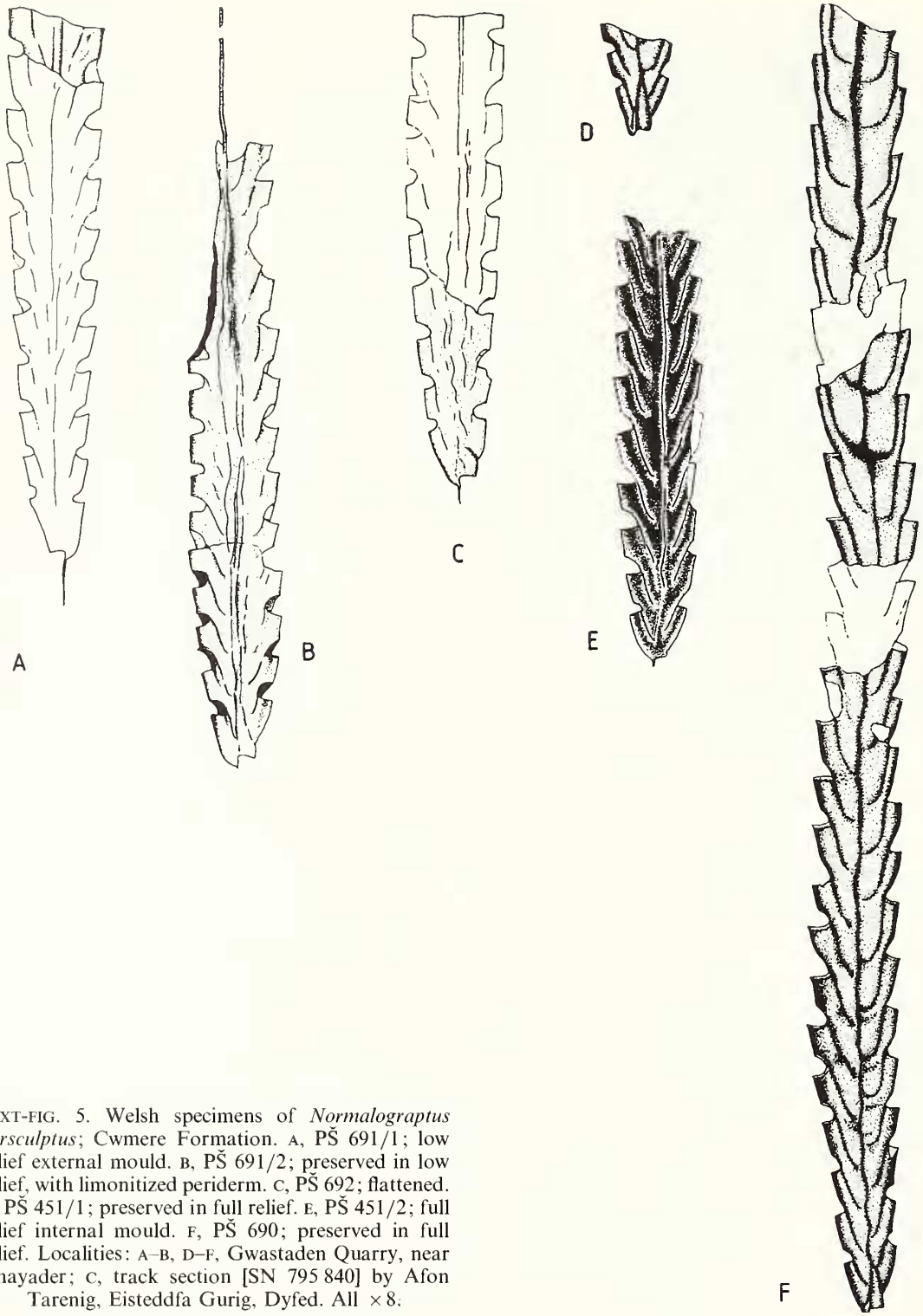


TEXT-FIG. 4. *Normalograptus persculptus* (Elles and Wood, 1907). A, PŠ 662a; four specimens preserved in low to moderate relief, with periderm. B, L 14651, holotype of '*G.*' *bohemicus*; flattened, partly limonitized film. C, PŠ 278/2; preserved in very low relief, with periderm. D, PŠ 451/2; full relief, internal mould. E, PŠ 690; full relief, internal mould. Localities: A, Pankrác, Bohemia; B–C, Jinonice-Nová Ves, Bohemia; D–E, Cwmere Formation, Gwastaden Quarry [SN 970 656], near Rhayader, Powys, Wales. All × 5.

Zalasiewicz and Tunnicliff (1994) assigned Hutt's (1974) specimens from the English Lake District to *N.*? *parvulus* (H. Lapworth). This species is significantly narrower than *N. persculptus* and post-dates it stratigraphically (see Zalasiewicz and Tunnicliff 1994 for details).

HIRNANTIAN GRAPTOLITE BIOZONATION

Jaeger (1977) figured '*G.*' *bohemicus* from the uppermost part of the Dobra Sandstone in Saxony (Germany). His material came from a level which corresponds approximately with the *bohemicus*-bearing beds in Bohemia. Most reports of the species, however, are from China, where it is usually assigned to *Diplograptus*. In China a *bohemicus* Biozone is widely recognized below the *persculptus* Biozone, being regarded as a stratigraphical equivalent of the *extraordinarius* Biozone (Li *et al.* 1983; Mu *et al.* 1983; Wang *et al.* 1984; Mu 1988). The index species is accompanied by faunas including *Paraorthograptus typicus* Mu, *Climacograptus supernus* Elles and Wood and *Normalograptus extraordinarius* (Sobolevskaya). The Chinese *bohemicus* Biozone is commonly separated from the succeeding *persculptus* Biozone by beds containing a rich, shelly *Hirnantia* fauna. According to Mu (1988), these beds correspond with the time of maximum Hirnantian glacio-eustatic regression and clearly precede the post-glacial transgressive sequence of the *persculptus*



TEXT-FIG. 5. Welsh specimens of *Normalograptus persculptus*; Cwmere Formation. A, PŠ 691/1; low relief external mould. B, PŠ 691/2; preserved in low relief, with limonitized periderm. C, PŠ 692; flattened. D, PŠ 451/1; preserved in full relief. E, PŠ 451/2; full relief internal mould. F, PŠ 690; preserved in full relief. Localities: A–B, D–F, Gwastaden Quarry, near Rhayader; C, track section [SN 795 840] by Afon Tarenig, Eisteddfa Gurig, Dyfed. All ×8.

TABLE 1. Measurements of dorso-ventral width, rhabdosome length, thecal count and thecal overlap in *Normalograptus persculptus*. Specimens are preserved flattened (F), in low to moderate relief (M) or full relief (R).

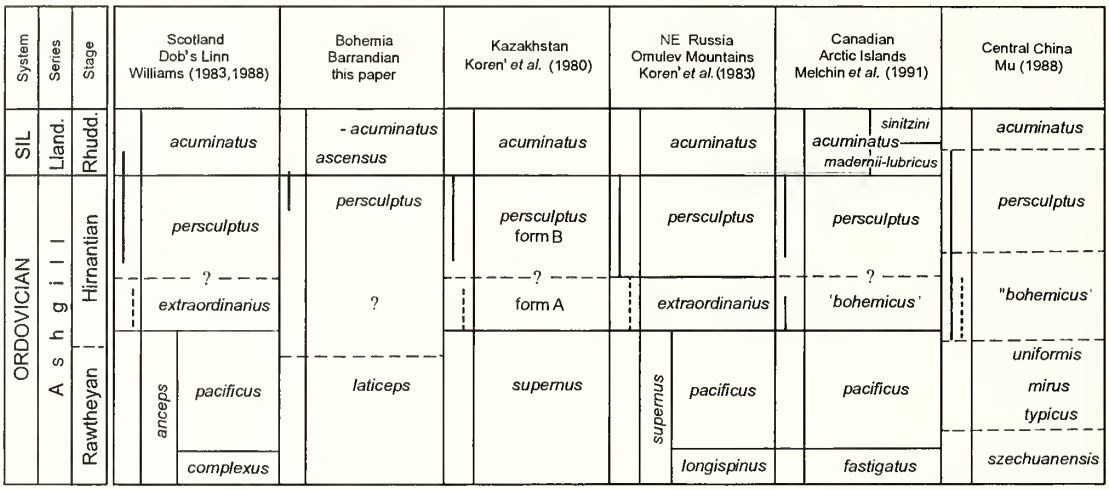
material, described by	preser-vation	width					length max.	thecal count		thecal overlap
		prox.	5th thecal pair	5 mm from prox.	10 mm from prox	dist. max.		/ prox. 5 mm	/ dist 10 mm	
persculptus Elles and Wood (1907)	M-R	1.0				2.0-2.5	> 30		8-10	1/2
persculptus Williams (1983)	M-R	1.0		1.5-1.7		2.0-2.7	30	5.5	9	
persculptus this paper (mid-Wales)	R	0.85-0.95	1.45		1.7-1.8	1.95	37	5-6	8.5-10	1/2
	F	0.95-1.15	1.55-1.75		1.8-1.95	2.2				
persculptus Bjerreskov (1975)	R	1.0	1.5			1.6	20	5	9.5-10	1/2
	F					2.0				
persculptus Koren and Sobolevskaya (1983)	F	1.05-1.25	1.7-1.8	1.85-2.0	1.9-2.2	2.25	45	5-5.5	9.5-10	1/2-1/3
persculptus forma B Koren et al. (1980)	M	1.0-1.1	1.5-1.7	1.6-1.75	1.75-2.0	2.0	35	5-6	9-10	1/2
	F				(2.5)	2.5				
'bohemicus' this paper (Bohemia)	M	0.8	1.45-1.6		1.6-1.7	2.35	28	5.5-5.8	10-10.5	1/2
	F	1.1-1.3	1.6-1.95		1.9-2.3					
'bohemicus' Mu and Lin (1984)	F	1.0-1.2		1.7	2.0	2.0	27	5.5	10	1/2
'bohemicus' Ge (1984)	F	1.4 (1.15-1.25)	1.6-1.7	1.8	2.2-2.3	2.3	20	5	8	1/2
'bohemicus' Li (1984)	F	1.0-1.2		1.8-2.0	2.1-2.2	2.2	>13	5-5.5		1/2-2/3
'bohemicus' Chen and Lin (1984)	F	1.0-1.2		2.0-2.1	2.0-2.1	2.2	27		10-11	1/2
persculptus Chen and Lin (1984)	F	1.0-1.5		1.5	1.7	2.1	22		10-11	1/2-2/3

Biozone. In Arctic Canada Melchin *et al.* (1991) found specimens of '*G.*' *bohemicus* just above beds which yielded *Paraorthograptus pacificus* (Ruedemann). The Bohemian specimens of '*G.*' *bohemicus* are almost certainly younger than those assigned to this taxon from Chinese and Canadian sequences.

Koren' and Sobolevskaya (1983) placed '*G.*' *bohemicus* into synonymy with *N. persculptus* after conducting a detailed study of the latter taxon from Siberia (Omulevka Uplift) and Kazakhstan (Koren' *et al.* 1980). Our study, primarily of Bohemian and Welsh specimens, confirms this synonymy. By contrast with the Chinese sections, where '*G.*' *bohemicus* and *N. extraordinarius* commonly occur together, in the sections described by Koren' *et al.* (1980) and Koren' and Sobolevskaya (1983) the earliest *N. persculptus* succeed the youngest specimens of *N. extraordinarius* without any overlap of their stratigraphical ranges.

With '*G.*' *bohemicus* being a junior synonym of *N. persculptus* it is clear that there is considerable diachroneity in the first occurrence of this species. In China and Arctic Canada *N. persculptus* appears as early as just above the *pacificus* Biozone, whilst in Siberia, Kazakhstan and Britain it appears above the *extraordinarius* Biozone.

The *bohemicus* Biozone should be omitted from future graptolite biozonal schemes. Where the first *N. persculptus* appears above the graptolite fauna of the *extraordinarius* Biozone (e.g. Great Britain, Kazakhstan, Siberia) the *persculptus* Biozone consists of the interval between the *extraordinarius* and *acuminatus* biozones (Text-fig. 6).



TEXT-FIG. 6. Correlation chart summarizing upper Ashgill graptolite biozonations and illustrating the stratigraphical ranges of *Normalograptus persculptus* (solid lines) and *N. extraordinarius* (dashed lines).

In peri-Gondwanan Europe (Bohemia, Saxony, Austrian Carnic Alps, Sardinia) a considerable gap in the graptolite record occurs below the *N. persculptus*-bearing horizon near the top of the Hirnantian. Here, the *extraordinarius* and *pacificus* biozones are entirely (or in Bohemia, almost entirely) represented by strata which are barren of graptolites.

The situation is more complicated in China and the Canadian Arctic where the *bohemicus* Biozone is succeeded by the *persculptus* Biozone. For example, the Chinese *bohemicus* Biozone, containing *N. persculptus* together with a fauna characteristic of the *extraordinarius* Biozone of Britain and the former USSR, could be either (1) assigned to the *extraordinarius* Biozone, despite the presence of *N. persculptus* (applying the assemblage zone concept as used by Elles 1925 and Rickards 1976), or (2) assigned to an expanded *persculptus* Biozone (on the basis that graptolite biozones should be defined by the first appearance of their index species, as suggested by Jaeger 1981, Štorch 1994 and Koren' *et al.* 1995) directly succeeding the *pacificus* Biozone; the *extraordinarius* Biozone would be relegated to subzonal status and would represent the lower portion of the *persculptus* Biozone. We prefer the latter option.

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REFERENCES

BJERRESKOV, M. 1975. Llandoverian and Wenlockian graptolites from Bornholm. *Fossils and Strata*, **8**, 1–94, pls 1–13.

BRENCHLEY, P. J. 1984. Late Ordovician extinctions and their relationship to the Gondwana Glaciation. 291–315. *In* BRENCHLEY, P. J. (ed.). *Fossils and climate*. John Wiley and Sons, London.

—— ROMANO, M., YOUNG, T. P. and ŠTORCH, P. 1991. Hirnantian glaciomarine diamictites – evidence for the spread of glaciation and its effect on Upper Ordovician faunas. 325–336. *In* BARNES, C. R. and WILLIAMS, S. H. (eds). Advances in Ordovician geology. *Paper of the Geological Survey of Canada*, **90–9**, 1–336.

—— and ŠTORCH, P. 1989. Environmental changes in the Hirnantian (Upper Ordovician) of the Prague Basin, Czechoslovakia. *Geological Journal*, **24**, 165–181.

CHEN XU and LIN YAO-KUN 1984. On the material of *Glyptograptus persculptus* (Salter) from the Yangzi Gorges, China. 191–200, pls 1–2. *In* NANJING INSTITUTE OF GEOLOGY AND PALAEONTOLOGY (compiler). *Stratigraphy and palaeontology of systemic boundaries in China, Ordovician-Silurian Boundary 1*. Anhui Science and Technology Publishing House, Anhui, 516 pp.

DAVIES, K. A. 1929. Notes on the graptolite faunas of the Upper Ordovician and Lower Silurian. *Geological Magazine*, **66**, 1–27.

ELLES, G. L. 1925. The characteristic assemblages of the graptolite zones of the British Isles. *Geological Magazine*, **62**, 337–347.

—— and WOOD, E. M. R. 1907. A monograph of British graptolites. Part 6. *Monograph of the Palaeontographical Society*, **61** (297), 217–272, pls 28–31.

FANG YI-TING, LIANG SHI-JING, ZHANG DA-LIANG and YU JIN-LONG 1990. *Stratigraphy and graptolite fauna of Lishuwo Formation from Wuning, Jiangxi*. Nanjing University Publishing House, Nanjing, 155 pp., 29 pls. [In Chinese with English summary].

FU LI-PU and SONG LI-SHENG 1986. Stratigraphy and palaeontology of Silurian in Ziyang Region (Transitional Belt). *Bulletin of the Xi'an Institute of Geology and Mineral Resources, Chinese Academy of Geological Sciences*, **14**, 1–198, pls 1–31. [In Chinese with English summary].

GE MEI-YU 1984. The graptolite fauna of the Ordovician-Silurian boundary section in Yuqian, Zhejiang. 389–444, pls 1–9. *In* NANJING INSTITUTE OF GEOLOGY AND PALAEONTOLOGY (compiler). *Stratigraphy and palaeontology of systemic boundaries in China, Ordovician-Silurian Boundary 1*. Anhui Science and Technology Publishing House, Anhui, 516 pp.

HAVLÍČEK, V. 1982. Ordovician in Bohemia: development of the Prague Basin and its benthic communities. *Sborník geologických věd, Geologie*, **37**, 103–136.

HUTT, J. E. 1974. The Llandovery graptolites of the English Lake District. Part 1. *Monograph of the Palaeontographical Society*, **128** (540), 1–56, pls 1–10.

JAEGER, H. 1977. Das Silur/Lochkov-Profil im Frankenberger Zwischengebirge (Sachsen). *Freiburger Forschungshefte, Reihe C*, **326**, 45–59.

—— 1981. Trends in stratigraphischer Methodik und Terminologie. *Zeitschrift für Geologische Wissenschaften*, **9**, 309–332.

KOREN', T. N., LENZ, A. C., LOYDELL, D. K., MELCHIN, M. J., STORCH, P. and TELLER, L. 1995. Generalized graptolite zonal sequence defining Silurian time intervals for global paleogeographic studies. *Lethaia*, **28**, 137–138.

—— MIKHAILOVA, N. F. and TZAI, D. T. 1980. Class Graptolithina. Graptolitit. 121–214. *In* APOLLONOV, M. K., BANDALETOV, S. M. and NIKITIN, I. F. (eds). *The Ordovician-Silurian boundary in Kazakhstan*. Nauka, Kazakh SSR Publishing House, Alma Ata, 300 pp. [In Russian].

—— and SOBOLEVSKAYA, R. F. 1977. Novaya etalonnaya posledovatelnost graptolitiv na granice ordovika i silura (Severo-Vostok SSSR). *Doklady Akademii Nauk SSSR*, **236**, 950–953. [In Russian].

—— —— 1983. Graptolity. 97–160, pls 25–47. *In* SOKOLOV, B. S., KOREN', T. N. and NIKITIN, I. F. (eds). *The Ordovician and Silurian boundary in the Northeast of the USSR*. Nauka, Leningrad, 208 pp, 48 pls. [In Russian with English summary].

LAPWORTH, C. 1877. On the graptolites of County Down. *Proceedings of the Belfast Naturalists' Field Club*, Appendix, 1876–77, 125–147, pls 5–7.

LEGRAND, P. 1987. Modo de desarrollo del suborden Diplograptina (Graptolithina) en el Ordovício superior y en el Silúrico. Implicaciones taxonómicas. *Revista Española de Paleontologia*, **2**, 59–64.

LI JI-JIN 1984. Graptolites across the Ordovician-Silurian boundary from Jingxian, Anhui. 309–370, pls 1–18. *In* NANJING INSTITUTE OF GEOLOGY AND PALAEONTOLOGY (compiler). *Stratigraphy and palaeontology of systemic boundaries in China, Ordovician-Silurian Boundary 1.* Anhui Science and Technology Publishing House, Anhui, 516 pp.

—— QIAN YI-YUAN and ZHANG JUN-MING 1983. Ordovician-Silurian boundary section at Beigong of Jingxian, Anhui Province. 123–129. *In Papers for the Symposium on the Cambrian-Ordovician and Ordovician-Silurian boundaries, Nanjing, China, October 1983.* Nanjing Institute of Geology and Palaeontology, Nanjing.

LIN YAO-KUN and CHEN XU 1984. *Glyptograptus persculptus* Zone – the earliest Silurian graptolite zone from Yangzi Gorges, China. 203–225, pls 1–6. *In* NANJING INSTITUTE OF GEOLOGY AND PALAEONTOLOGY (compiler). *Stratigraphy and palaeontology of systemic boundaries in China, Ordovician-Silurian Boundary 1.* Anhui Science and Technology Publishing House, Anhui, 516 pp.

MAREK, L. 1955. *Glyptograptus bohemicus* n. sp. z vrstev kosovskych (dξ2). *Sborník Ústředního ústavu geologického. Oddíl Paleontologicky*, **24**, 382–384.

—— and HAVLÍČEK, V. 1967. The articulate brachiopods of the Kosov Formation (upper Ashgillian). *Věstník Ústředního ústavu geologického*, **42**, 275–284.

MELCHIN, M. J., MCCRACKEN, A. D. and OLIFF, F. J. 1991. The Ordovician-Silurian boundary on Cornwallis and Truro islands, Arctic Canada: preliminary data. *Canadian Journal of Earth Sciences*, **28**, 1854–1862.

—— and MITCHELL, C. E. 1991. Late Ordovician extinction in the Graptoloidea. 143–156. *In* BARNES, C. R. and WILLIAMS, S. H. (eds). Advances in Ordovician geology. *Paper of the Geological Survey of Canada*, **90–9**, 1–336.

MIKHAYLOVA, N. F. 1973. Graptolity verchnego ordovika i nizhnego silura Kazakhstana. 14–19. *In Novoe v paleontologii Sibiri i Srednej Azii.* Nauka, Novosibirsk, 143 pp.

MIKULÁS, R. 1993. Trace fossils from the Kosov Formation of the Bohemian Upper Ordovician. *Sborník Geologických Věd, Paleontologie*, **32**, 9–54.

MU EN-ZHI 1988. The Ordovician-Silurian boundary in China. *In* COCKS, L. R. M. and RICKARDS, R. B. (eds). A global analysis of the Ordovician-Silurian Boundary. *Bulletin of the British Museum* (*Natural History*), *Geology series*, **43**, 117–131.

—— LI JI-JIN, GE MEI-YU, CHEN XU, LIN YAO-KUN and NI YU-NAN 1993. Upper Ordovician graptolites of Central China region. *Palaeontologia Sinica*, **182**, *Series B*, (29), 1–393. [In Chinese with English summary].

—— and LIN YAO-KUN 1984. Graptolites from the Ordovician-Silurian boundary sections of Yichang area, W. Hubei. 45–73, pls 1–8. *In* NANJING INSTITUTE OF GEOLOGY AND PALAEONTOLOGY (compiler). *Stratigraphy and palaeontology of systemic boundaries in China, Ordovician-Silurian Boundary 1.* Anhui Science and Technology Publishing House, Anhui, 516 pp.

—— ZHU ZHAO-LING, LIN YAO-KUN and WU HONG-JI 1983. Ordovician-Silurian Boundary of Yichang, Hubei. 94–106, 4 pls. *In Papers for the Symposium on the Cambrian-Ordovician and Ordovician-Silurian boundaries, Nanjing, China, October 1983.* Nanjing Institute of Geology and Palaeontology, Nanjing.

NI YU-NAN 1984. Upper Ordovician graptolites from Baoshan, Western Yunnan. *Acta Palaeontologica Sinica*, **23**, 320–327. [In Chinese with English summary].

RICKARDS, R. B. 1976. The sequence of Silurian graptolite zones in the British Isles. *Geological Journal*, **11**, 153–188.

—— HUTT, J. E. and BERRY, W. B. N. 1977. Evolution of the Silurian and Devonian graptoloids. *Bulletin of the British Museum* (*Natural History*), *Geology Series*, **28**, 1–120, pls 1–6.

SALTER, J. W. 1865. *In* HUXLEY, T. H. and ETHERIDGE, R. A. (eds). *A catalogue of the collection of fossils in the Museum of Practical Geology.* London, 381 pp.

SENNIKOV, N. V. 1978. O nakhodke graptolitov zony *persculptus* na Gornom Altaye. 141–144. *In Novoe v stratigrafii i paleontologii nizhnego paleozoya Sredny Sibiri.* Nauka, Novosibirsk. [In Russian].

ŠTORCH, P. 1982. Ordovician-Silurian boundary in the northernmost part of the Prague Basin (Barrandian, Bohemia). *Věstník Ústřdního ústavu geologického*, **57**, 231–236.

—— 1986. Ordovician-Silurian boundary in the Prague Basin (Barrandian area, Bohemia). *Sborník Geologických Věd, Geologie*, **41**, 69–103.

—— 1988. Ordovician-Silurian boundary in Bohemia (Prague Basin). *In* COCKS, L. R. M. and RICKARDS, R. B. (eds). A global analysis of the Ordovician-Silurian Boundary. *Bulletin of the British Museum* (*Natural History*), *Geology Series*, **43**, 95–100.

—— 1990. Upper Ordovician-lower Silurian sequences of the Bohemian Massif, central Europe. *Geological Magazine*, **127**, 225–239.

—— 1994. Graptolite biostratigraphy of the Lower Silurian (Llandovery and Wenlock) of Bohemia. *Geological Journal*, **29**, 137–165.

—— and MERGL, M. 1989. Královdvor-Kosov boundary and the late Ordovician environmental changes in the Prague Basin (Barrandian area, Bohemia). *Sborník Geologických Věd, Geologie*, **44**, 117–153.

—— and SERPAGLI, E. 1993. Lower Silurian graptolites from southwestern Sardinia. *Bolletino della Societa Paleontologica Italiana*, **32**, 3–57.

STRACHAN, I. 1971. A synoptic supplement to "A monograph of British graptolites by Miss G. L. Elles and Miss E. M. R. Wood." *Monograph of the Palaeontographical Society*, **125** (529), 1–130.

VANDENBERG, A. H. M., RICKARDS, R. B. and HOLLOWAY, D. J. 1984. The Ordovician-Silurian boundary at Darrawit Guim, central Victoria. *Alcheringa*, **8**, 1–22.

WANG XIAO-FENG 1987. Graptolite biostratigraphy of the Yangtze Gorge area. 364–386. *In* WANG XIAO-FENG, NI SHI-ZHAO, ZENG QING-LUAN, XU GUANG-HONG, ZHOU TIAN-MEI, LI ZHI-HONG, XING LI-WEN and LAI CAI-GEN. *Biostratigraphy of the Yangtze Gorge area* (*2*). Geological Publishing House, Beijing, 641 pp., 72 pls. [In Chinese with extended English abstract].

ZENG QING-LUAN, ZHOU TIAN-MEI, SUN QUAN-YING, LI ZHI-HONG, XING LI-WEN and LAI CAI-GEN 1983. Latest Ordovician and earliest Silurian faunas from the eastern Yangtze Gorges with comments on Ordovician-Silurian boundary. *Bulletin of the Yichang Institute of Geology and Mineral Resources*, **6**, 57–163. [In Chinese with English abstract].

WILLIAMS, S. H. 1983. The Ordovician-Silurian boundary graptolite fauna of Dob's Linn, southern Scotland. *Palaeontology*, **26**, 605–639, p. 66.

ZALASIEWICZ, J. and TUNNICLIFF, S. 1994. Uppermost Ordovician to Lower Silurian graptolite biostratigraphy of the Wye Valley, central Wales. *Palaeontology*, **37**, 695–720.

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